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	Patents ADP Number (*if you know it*)	07419294001
	If the applicant is a corporate body, give the country/state of its incorporation	THE NETHERLANDS
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DESCRIPTION

DEVICE AND METHOD OF MAKING A DEVICE HAVING A PATTERNED LAYER ON A FLEXIBLE SUBSTRATE

This application relates to the field of flexible devices, particularly but not exclusively to flexible electronic devices including flexible electronic displays. More particularly, this application relates to the topographical shape of a layer on a flexible substrate, wherein the topographical shape of the layer enables it to withstand higher levels of strain before fracture than conventional layers.

Flexible substrates are substrates that may be deformed whilst maintaining their functional integrity. They can, for example, be made of plastic, metal foil or very thin glass; in general they will have a low elastic modulus or be relatively thin. The development of flexible substrates allows greater freedom in the design of electronic devices and thus enables the development of previously impracticable electronic appliances in numerous areas of technology. One example is the development of flexible electronic displays. These have numerous benefits over the rigid devices that are currently available. Curved or roll-up displays could be developed which are cheap enough to manufacture and have sufficient flexibility and durability such that they could, one day, rival paper.

A limitation to the production of flexible displays is that the flexible substrates often require coatings of more brittle materials. An example of one of these materials is the Indium Tin Oxide (ITO) electrode used in liquid crystal displays (LCDs) such as passive matrix LCD displays. An example of the use of ITO in LCDs is provided in US-A-5,130,829. Brittle materials, such as ITO, fracture when exposed to strains above a certain limit and thus lose functionality. Due to its brittleness, when strained, ITO is likely to crack or delaminate, having the effect of reducing its conductivity. This greatly inhibits the performance of the display.

WO-A-96/39707 describes an electrode for use on flexible substrates, which is designed to retain more of its conductivity for greater amounts of strain. To achieve this, a coating of a second more flexible conductive material is applied such that it is in contact with the relatively brittle electrode material. Accordingly, when the brittle electrode is put under strain and therefore starts to crack, electrical continuity is maintained via the second, more flexible material.

The drawback of this approach is that the second material has a much greater resistivity than the brittle electrode material. The price for increased flexibility is an increase in resistance of the electrode and accordingly this approach is not applicable where good electrode conductivity is required, such as in electronic displays.

WO-A-02/45160 describes a flexible metal connector for providing a link between rigid substrate portions. A cross-sectional view of a flexible substrate 1 having a connector 2 with a similar structure to that described in WO-A-02/45160 is shown in Figure 1. The connector 2 is formed by first and second troughs 3, 4 connected by a ridge 5. The base 3a, 4a and one side 3b, 4b of each of the first and second troughs are in contact with the substrate 1. However, the other side 3c, 4c of each of the first and second troughs and the ridge 5 connecting the troughs 3, 4 are not in contact with the substrate 1.

The structure of the connector 2 is such that it is able to flex in a concertina-like manner when strained and thus may withstand larger amounts of strain before fracture than conventional connectors. However, using this particular structure for brittle materials is inappropriate because, as longitudinal strain is applied to the brittle conductor material, there would be a concentration of stress in the corners of the connector 2, for example the left-hand corner 6 of the ridge 5, causing the material to fracture.

Furthermore, a connector such as that of WO-A-02/45160, having raised bridging portions, would require several photolithographic steps for its manufacture, as are described in WO-A-02/45160. For example, in one process, the first step would be the deposition of a layer of photoresist onto the surface of the substrate 1. This would then be patterned to leave three blocks,

one 7 marking the left-hand boundary of the connector 2, one 8 marking the right-hand boundary and the last 9 formed to shape the ridge 5 of the connector 2. The next step would be that of depositing a thin electroplating seed layer, for instance copper over chromium, to the substrate, covering the blocks of photoresist 7, 8, 9 and the exposed substrate. The connector 2 would then be electroplated over the seed layer. In a final stage, the photoresist blocks 7, 8, 9 are removed.

These steps required for the fabrication of the connector 2 of figure 1 add time and expense to the production process of flexible devices. Also, for certain applications, substrates having a raised topography, such as that which would be necessary for ITO layers formed using the approach of WO-A-02/45160, are undesirable. One example of this is LCDs, for which it is preferable to limit substrate thickness.

The present invention aims to address the above problems. According to a first aspect of the invention there is provided a device comprising first and second layers wherein the first layer is flexible and the second layer is substantially flat and meanders across the plane of the first layer so as to prevent fracture of the second layer when the first layer is deformed.

The shape of the second layer may enable it to be more flexible than conventional non-meandering layers, while maintaining a relatively thin structure overall. A flat second layer is also easier to fabricate than the prior art structures described above.

The second layer may be in contact with the first layer over substantially the whole of the length of the second layer.

The second layer may further comprise a plurality of interconnected portions wherein the portions are arranged in aligned sets offset from one another, the portions being connected to one another so as to provide a continuous path between first and second ends of the second layer.

Each of the portions may be connected to one another by a connecting element which may be narrower than the portions being connected. This may

minimise the risk of fracture further and enable the structure to better resist twisting motions during deformation.

Each of the portions may have a predetermined length, the portion length being selected to prevent fracture when the first layer is deformed to a predetermined radius of curvature. The portion length may be selected to be less than a predetermined length, the predetermined length being dependent on the average length between cracks for a continuous layer deformed to the predetermined radius of curvature.

Having the lengths of the portions determined in this way enables the portions to be fabricated such that they are of a length that is unlikely to crack or delaminate when the first layer is deformed to a predetermined radius of curvature.

According to a second aspect of the invention there is provided a method of fabricating a device comprising first and second layers wherein the first layer is flexible and the second layer is substantially flat and meanders across the plane of the first layer so as to prevent fracture of the second layer when the first layer is deformed, the second layer comprising a plurality of interconnected portions each having a portion length, the method including selecting the portion length to prevent fracture when the first layer is deformed to a predetermined radius of curvature.

The method may further comprise determining a spacing between cracks for a continuous layer of material which forms the first layer, when deformed to a predetermined radius of curvature, and selecting the portion length to be a value that is dependent on the determined spacing and/or determining an average spacing between the cracks.

For a better understanding of the invention, embodiments thereof will now be described, purely by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view of a prior art connector on a flexible substrate;

Figure 2 is a plan view of a meandering layer on a flexible substrate according to the invention;

Figure 3 is a cross-sectional view of a functional layer on a flexible substrate;

Figure 4 is a cross-sectional view of a functional layer on a flexible substrate under strain;

Figure 5 is a plan view of a conventional ITO layer on a flexible substrate that has undergone bending;

Figure 6 is a plan view of a layer having undulating portions on a flexible substrate according to the invention;

Figure 7 is a plan view of an undulating layer on a flexible substrate according to the invention;

Figure 8 is a plan view of a layer comprising an array of portions on a flexible substrate according to another aspect of the invention;

Figure 9 is a plan view of a layer comprising randomly distributed portions on a flexible substrate according to a further aspect of the invention; and

Figure 10 is a plan view of a line geometry for an electrode for an active matrix liquid crystal display device in accordance with the invention.

Referring to Figure 2, a portion of the structure of a flexible liquid crystal display (LCD) is illustrated in plan view. This comprises a first layer 10 and a second layer 11. In this example, the second layer 11 is a layer of Indium Tin Oxide (ITO), which is a brittle material used for conductor lines in LCDs. Other brittle layers having other functions could form the second layer. The ITO layer 11 forms a conductor line that travels in what is referred to here as a longitudinal direction across the first layer 10 and is supported along its length by the first layer 10, which, in this example, is a polycarbonate substrate. The ITO layer 11 comprises first and second sets of rectangular portions 12, 13 aligned in the longitudinal direction, one set being offset from the other in the longitudinal direction. The sets are also spaced apart from each other by a predetermined distance 14. Each end of each of the rectangular portions of

the first set 12 is connected to an end of a rectangular portion of the second set 13 by a relatively narrow connecting portion 15, such that the ITO layer 11 has electrical continuity along its length. The ITO layer 11 thus has a meandering shape. The rectangular portions of the first and second sets have lengths 21 of 300μm and widths 22 of 100μm. This may of course vary depending on the application.

Figure 3 illustrates a cross-sectional view of the portion of the LCD depicted in Figure 2. The substrate 10 is flexible and, in particular, the centre portion 16 may move up and down in relation to the end portions 17, 18, as depicted by the double-ended arrow 19. In this manner, the substrate 10 may be bent to have a certain radius of curvature r.

Figure 4 is a cross-sectional view of the LCD portion of Figures 2 and 3 when under strain. When the substrate 10 is strained, stress is exerted on the substrate 10, the stress being at its greatest at the upper and lower surfaces of the substrate 10, the upper surface being that on which the ITO layer 11 is applied. Depending on the direction of movement of the centre portion 16 in relation to the ends 17, 18, either a compressive or tensile stress will be exerted on the upper surface of the substrate 10. This will cause a strain in the brittle ITO layer 11.

The meandering structure of the ITO layer 11 enables it to withstand higher strains before fracture than would otherwise be possible. This gives the layer "concertina-like" properties, such that the portions 12, 13 can move in relation to each other in the longitudinal direction as illustrated by the arrows 20 in Figure 2, to reduce or increase the longitudinal length of the ITO layer 11 and thus enable it to absorb larger longitudinal strains. The terms "longitudinal strain" and "longitudinal length" used throughout this specification refer to strains and lengths across the substrates as shown in the Figures, for instance from the left-hand end 17 to the right-hand end 18 of the substrate 10 illustrated in Figure 2.

The functional layer 11 may be any of numerous brittle functional coatings, such as a scratch-resistant coating, a solvent or gas resistant coating, or a conductive coating such as Transparent Conductive Oxide

(TCO), an example being Indium Tin Oxide (ITO). These coatings generally have higher values of Young's Modulus to those of the materials used for the substrate 10. Accordingly, they are more likely to fracture when strains, at which the substrate 10 may be stable, are exerted on them.

The thickness of the functional layer 11 and of the flexible substrate 10 are dependent on the particular application and the materials used. In the case of an LCD having a flexible polycarbonate substrate with an ITO electrode layer, the thickness of the substrate is likely to be to the order of 0.1 to 1mm, with an ITO layer thickness of 50 to 200nm.

The functional layer 11 may, for example, be formed by vacuum deposition, for example spluttering or vapour deposition, followed by photolithographic patterning. Alternatively, a printing technique such as ink-jet printing, soft lithographic techniques such as microcontact printing, flexographic printing or screen printing may be used. The specific processes involved in these methods and other methods for applying the functional layer 11 would be apparent to the skilled person. The choice of method and processes involved in the chosen method will depend on the exact material required for the functional layer 11.

Due to the fact that the functional layer 11 has no raised topographical structure, unlike the connector 2 of Figure 1, the steps involved in producing it are relatively simple in comparison to those necessary to produce more complicated structures having the same purpose. Also, the layer thickness is minimal, which is an advantage in the fabrication of devices where minimising overall substrate thickness is desirable. One such example is the fabrication of LCDs.

As is shown in Figure 3, the resulting structure of layer 11 is supported along its length by the substrate 10. This property ensures that the layer 11 is robust.

The lengths 21 of the long sides of the rectangular portions 12, 13 of the functional layer 11 will influence the properties of the functional layer 11 when under strain. When crack formation in an ITO line on a flexible substrate undergoing tensile or bending tests is analysed, a statistical pattern emerges.

For a certain radius of curvature of the flexible substrate, the ITO line may, for example, crack perpendicularly at roughly 300μm intervals. However, each of the 300μm sections thus formed will then be stable and will not exhibit further cracking until the substrate undergoes a further change to a smaller radius of curvature. Hence, for each radius of curvature to which the flexible substrate is bent, there is a length of ITO line that will be stable and therefore less likely to crack.

Figure 5 is a plan view of a conventional ITO layer 23 on a flexible substrate 24 following deformation to a specific radius of curvature. As can be seen, cracks 25 have formed at intervals along the length of the ITO layer 23. The average distance between these cracks is dependent on the radius of curvature of the substrate 24. At a certain radius of curvature, r, of the substrate 24, the distance between the cracks (such as the distances A, B and C) may be measured. An average may then be taken of these values. A critical length, above which continuous portions of brittle layers on the flexible substrate when bent to radius r are likely to fracture, will be dependent on this average length. In practice, it has been found that the critical length for continuous portions may be up to three times the average length. Accordingly, the lengths 21 of the continuous portions 12, 13 of the ITO layer 11 are set to be no greater than the critical length, making the layer less likely to fracture when the substrate 10 is bent up to the radius of curvature r.

Figure 6 is a plan view of a flexible substrate 26 having a functional layer 27, similar to that shown in Figure 2. The layer 27 comprises first and second sets of essentially semicircular portions 28, 29 aligned in the longitudinal direction, one set being offset from the other in the longitudinal direction. The sets are also spaced apart from each other by a certain distance. Each end of each of the semicircular portions of the first set is connected to an end of a semicircular portion of the second set by a relatively narrow connecting portion 30, such that the ITO layer 27 has electrical continuity along its length. The ITO layer 27, in a similar manner to the layer 11 of Figure 2, thus has a meandering shape.

Having curved portions 28, 29 rather than rectangular portions 12, 13 improves the properties of the functional layer 27 when strained. The functional layer 11 of Figure 2 is more likely to have large stresses at the intersections of adjoining rectangular portions, such as the right-hand intersection 31, causing it to fracture at these points. Stresses in the functional layer 27 of Figure 6 will be more evenly distributed throughout the layer 27, due to its curved topographical shape. This topographical shape is therefore less likely to fracture.

The length 31 of the semicircular portions in one example is set to be no greater than the critical length previously described, making the undulated layer 27 less likely to fracture when the substrate 26 is bent up to the radius of curvature r.

Both the functional layer 11 of Figure 2 and the functional layer 27 of Figure 6 comprise narrow connecting portions 15, 30 respectively that run perpendicularly to the longitudinal direction of the ITO layers 11, 27. These are made narrow such that their widths are well below the critical length discussed above and hence they are very unlikely to fracture. These connecting portions 15, 30 may also twist as their ends are forced to rotate in different directions, due to the strains exerted on the functional layers 11, 27. The fact that they are narrow also reduces the likelihood that they will fracture as a result of such twisting. In alternative embodiments wider connection portions may be used. For example, Figure 7 illustrates an embodiment in which a substrate 32 has a functional layer 33, wherein the connecting portions are effectively of the same width 34 as the curved portions 35. The curved portions 35 may have a length 36 that is set to be no greater than the critical length previously described.

Also, in further embodiments, the joints between connecting portions 15, 30 and rectangular portions 12, 13 or semicircular portions 28, 29 have rounded corners to more evenly distribute forces at the corners of these joints. The connecting portions 15, 30 are also not limited to being disposed perpendicularly to the longitudinal direction, but may be at an angle such as 45 degrees to the longitudinal direction.

The methods for applying the functional layers 27, 33 having undulating shapes to the substrates 26, 32 and the thickness of the resulting layers 27, 33, are similar to those discussed previously.

From reading the present disclosure, other variations and modifications will be apparent to persons skilled in the art. Such variations and modifications may involve equivalent and other features which are already known in the design, manufacture and use of flexible electronic devices and which may be used instead of or in addition to features already described herein.

In particular, the invention is not limited to use in an LCD display, nor to a polycarbonate substrate. It is also applicable to any flexible substrate having a functional coating. It is also applicable to other types of display, such as foil displays, e-ink displays, poly-LED displays, O-LED displays and other electroluminescent displays.

Also, the shape of the portions 12, 13, 28, 29 that form the layers 11, 27, in accordance with the invention, may differ from the rectangular and semicircular shapes illustrated in the Figures.

The layers may comprise three or more sets of such portions, each offset and/or spaced apart from the others. Figure 8 illustrates in plan view one such embodiment of the invention in which a substrate 37 is coated with a functional layer 38 comprising an array of rectangular portions 39. Each rectangular portion 39 is connected to surrounding portions via connecting portions 40. In this embodiment, both the length 41 and width 42 of the rectangular portions 39 may be set to be no greater than the critical length previously described. Accordingly, this layer 39 will be less likely to fracture when strains are applied to it in either the longitudinal direction, illustrated by the arrow 43 in Figure 8 or in a direction perpendicular to the longitudinal direction.

In further embodiments, portions may be randomly distributed such that the second layer is non-symmetrical, which may assist in the avoidance of the propagation of systematic fracture within the layer. Figure 9 illustrates a plan view of a substrate 43 having a functional layer 44 comprising randomly distributed interconnected portions 45.

The portions may also be positioned on a substrate and have sizes that are determined in accordance with the position of LCD pixels on the substrate. An example of an electrode line geometry for an active-matrix display on a flexible substrate 46 is shown in Figure 10. An electrode 47 passes to the left of a first pixel 48, to the right of a second pixel 49 and then to the left of a third pixel 50. The period of the meander of the electrode 47 is determined by the spacing between the pixels. In alternative embodiments, the electrode 47 passes to one side of two or more pixels, before switching to the other side of the pixels, so producing a period which is an integer multiple of the spacing between the pixels. An irregular electrode meander can also be used, for example, passing one pixel on a first side, three on the second side, then two on the first side and so on. Numerous other arrangements would be apparent to the skilled person.

Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure of the present invention also includes any novel features or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

CLAIMS

1. A device comprising first (10, 26, 32, 37, 43) and second (11, 27, 33, 38, 44) layers wherein:

the first layer is flexible; and

the second layer is substantially flat and meanders across the plane of the first layer so as to prevent fracture of the second layer when the first layer is deformed.

2. A device according to claim 1, wherein the second layer (11, 27, 33, 38, 44) is in contact with the first layer (10, 26, 32, 37, 43) over substantially the whole of the length of the second layer.

3. A device according to claim 1 or 2, wherein the second layer (11, 27, 33, 38, 44) comprises a plurality of interconnected portions (12, 13, 28, 29, 35, 39, 45).

4. A device according to claim 3, wherein the portions (12, 13, 28, 29, 35, 39, 45) are arranged in aligned sets, the portions being connected to one another so as to provide a continuous path between first and second ends of the second layer.

5. A device according to claim 4, comprising two aligned sets of interconnected portions (12, 13, 28, 29, 35).

6. A device according to claims 4 or 5, wherein the aligned sets are offset from one another.

7. A device according to any one of claims 3 to 6, wherein the portions (12, 13, 28, 29, 35, 39) are connected to one another at their respective ends.

8. A device according to any one of claims 3 to 7, wherein each of the portions (12, 13, 28, 29, 39, 45) are connected to one another by a connecting element (15, 30) which is narrower than the portions being connected.

9. A device according to claim 8, wherein the portions (12, 13, 28, 29, 39) are aligned in a longitudinal direction and the connecting element (15, 30) is disposed to be substantially perpendicular to said direction.

10. A device according to any one of claims 3 to 9, wherein the interconnected portions (12, 13, 39, 45), comprise rectangular portions.

11. A device according to any one of claims 3 to 9, wherein the interconnected portions (28, 29, 35) comprise semi-circular portions.

12. A device according to claim 3, wherein the second layer (44) comprises a random arrangement of portions (45) connected to one another so as to provide a continuous path between first and second ends of the second layer.

13. A device according to any one of claims 3 to 12, wherein each of the portions (12, 13, 28, 29, 35, 39, 45) has a length, the portion length (21, 31, 36, 41) being selected to prevent fracture when the first layer (10, 26, 32, 37, 43) is deformed to a predetermined radius of curvature.

14. A device according to claim 13, wherein the portion length (21, 31, 36, 41) is selected to be less than a predetermined length, the predetermined length being dependent on the average length between cracks (25) for a continuous layer deformed to the predetermined radius of curvature.

15. A device according to any one of the preceding claims, wherein the first layer (10, 26, 32, 37, 43) is a substrate.

16. A device according to claim 15, wherein the substrate comprises polycarbonate.

17. A device according to any one of the preceding claims, wherein the second layer (11, 27, 33, 38, 44) is a coating on the first layer (10, 26, 32, 37, 43).

18. A device according to claim 17, wherein the second layer (11, 27, 33, 38, 44) comprises a transparent conductor.

19. A device according to claim 17 or 18, wherein the second layer (11, 27, 33, 38, 44) comprises a conductive oxide.

20. A device according to claim 19, wherein the conductive oxide comprises indium tin oxide.

21. A device according to any one of claims 3 to 20, wherein the portions (12, 13, 28, 29, 35, 39, 45) are interconnected to provide a continuous path for an electric current.

22. A device according to any one of the preceding claims, comprising a display.

23. A device according to claim 22, comprising an electroluminescent display.

24. A device according to claim 22, comprising a foil display.

25. A device according to claim 22, comprising a liquid crystal display device.

26. A device according to claim 25, wherein each of the portions (12, 13, 28, 29, 35, 39, 45) has a length, the portion length (21, 31, 36, 41) being dependent on the spacing and size of pixels in the liquid crystal display device.

27. A device according to claim 25 or 26, wherein the liquid crystal display device comprises an active matrix device.

28. A device according to claim 27, wherein the active matrix liquid crystal display device comprises a plurality of spaced apart pixels (48, 49, 50) and the second layer comprises an electrode (47) which is arranged to meander periodically between the pixels, the period of the meander being dependent on the pixel spacing.

29. A device according to claim 28, wherein the period of the meander is an integer multiple of the pixel spacing.

30. A device according to any one of the preceding claims, wherein the second layer (11, 27, 33, 38, 44) comprises a brittle material.

31. A method of fabricating a device comprising first (10, 26, 32, 37, 43) and second (11, 27, 33, 38, 44) layers wherein the first layer is flexible and the second layer is substantially flat and meanders across the plane of the first layer so as to prevent fracture of the second layer when the first layer is deformed, the second layer comprising a plurality of interconnected portions (12, 13, 28, 29, 35, 39, 45) each having a portion length (21, 31, 36, 41), the method including selecting the portion length to prevent fracture when the first layer is deformed to a predetermined radius of curvature.

32. A method according to claim 31, further comprising determining a spacing between fractures (25) for a continuous layer (24) of material when deformed to a predetermined radius of curvature, and selecting the portion length to be a value that is dependent on the determined spacing.

33. A method according to claim 32, comprising determining an average spacing between the fractures (25).

34. A device comprising first and second layers substantially as hereinbefore described with reference to the accompanying drawings.

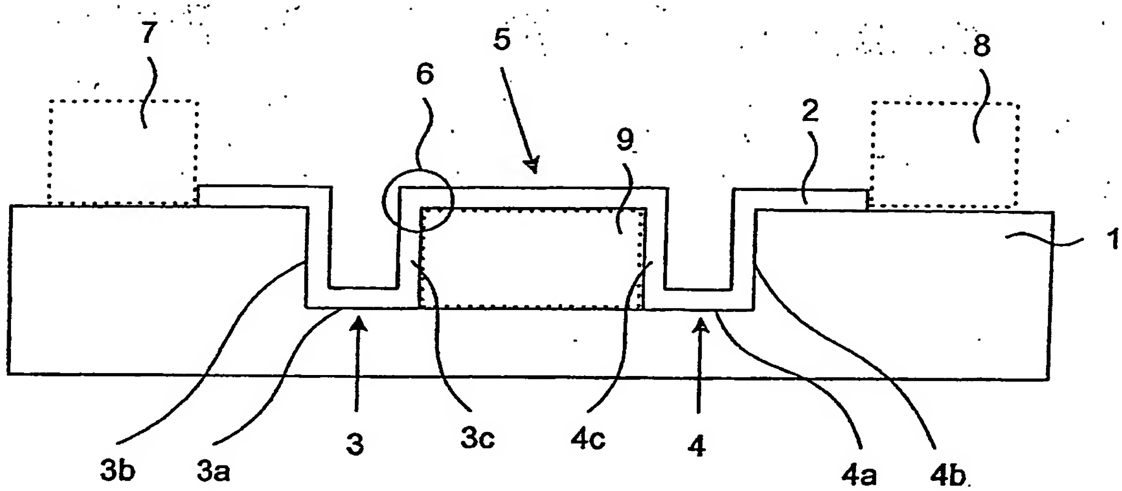
35. A method of fabricating a device comprising first and second layers substantially as hereinbefore described with reference to the accompanying drawings.

ABSTRACT

DEVICE AND METHOD OF MAKING A DEVICE HAVING A PATTERNED LAYER ON A FLEXIBLE SUBSTRATE

A device such as a flexible LCD is described comprising first and second layers wherein the first layer is a flexible substrate and the second layer is a brittle ITO conduction line applied to the substrate. The ITO layer is substantially flat and meanders across the plane of the flexible substrate so as to prevent fracture of the ITO layer when the flexible substrate is deformed. The ITO layer may be subdivided into portions, the length of the portions being selected to prevent fracture when the flexible substrate is deformed to a predetermined radius of curvature.

[Fig. 2]



PRIOR ART

Fig. 1

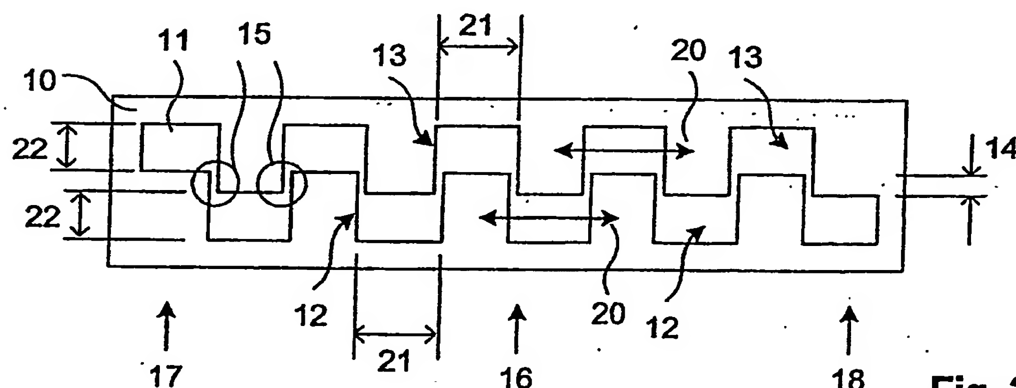


Fig. 2

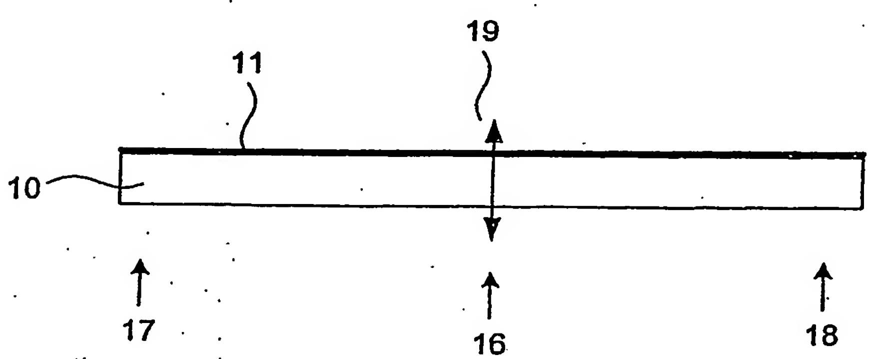


Fig. 3

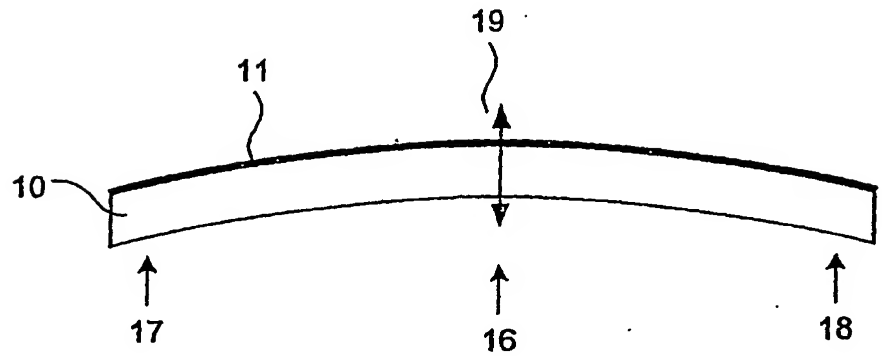


Fig. 4

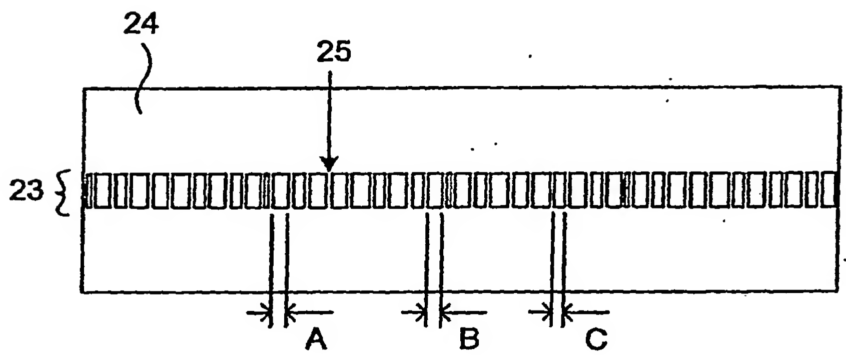


Fig. 5

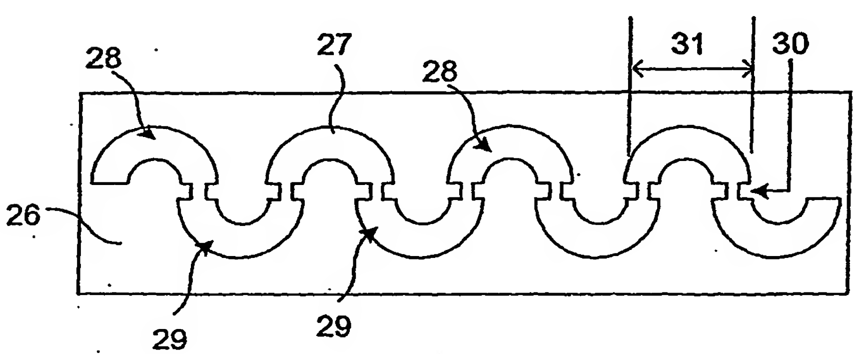


Fig. 6

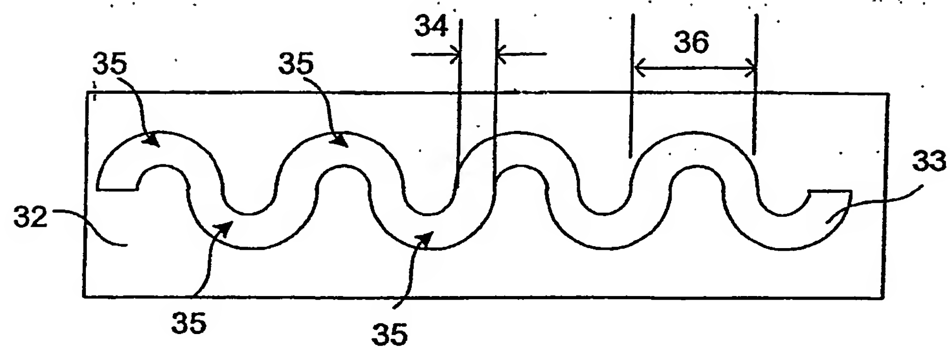


Fig. 7

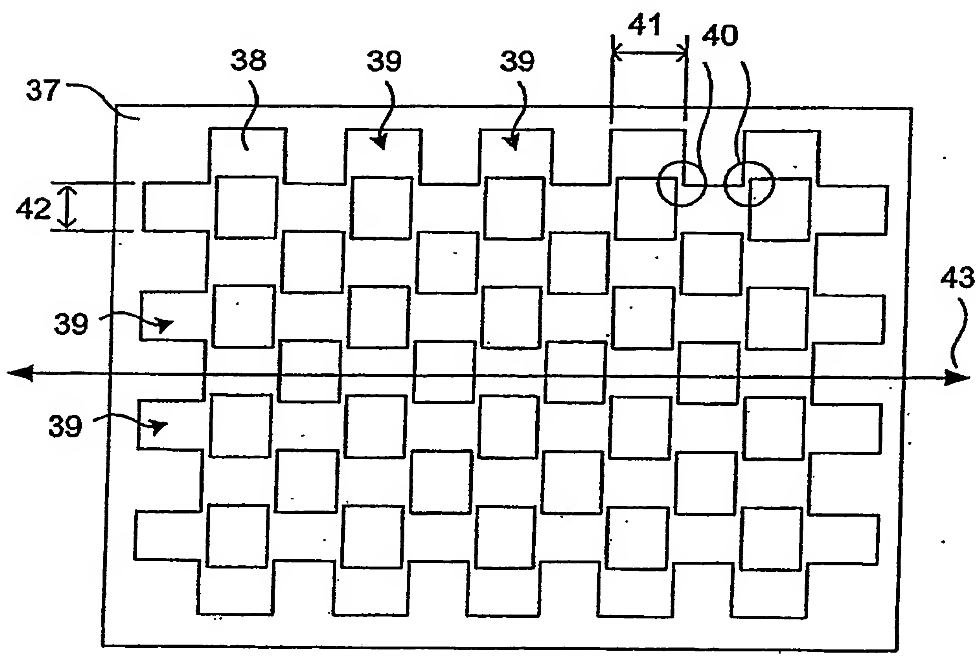


Fig. 8

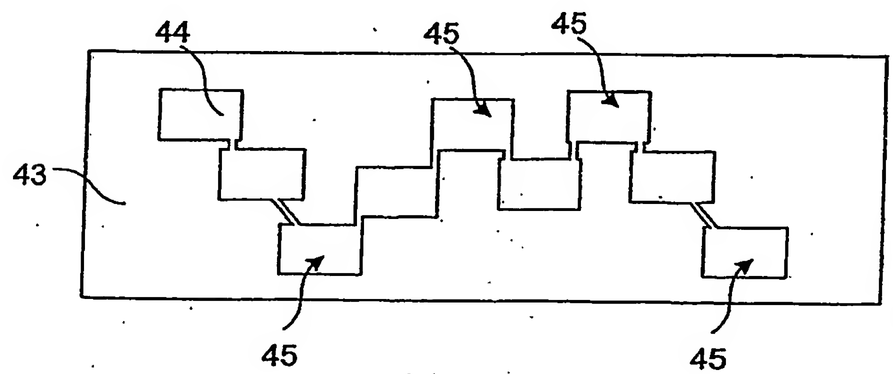


Fig. 9

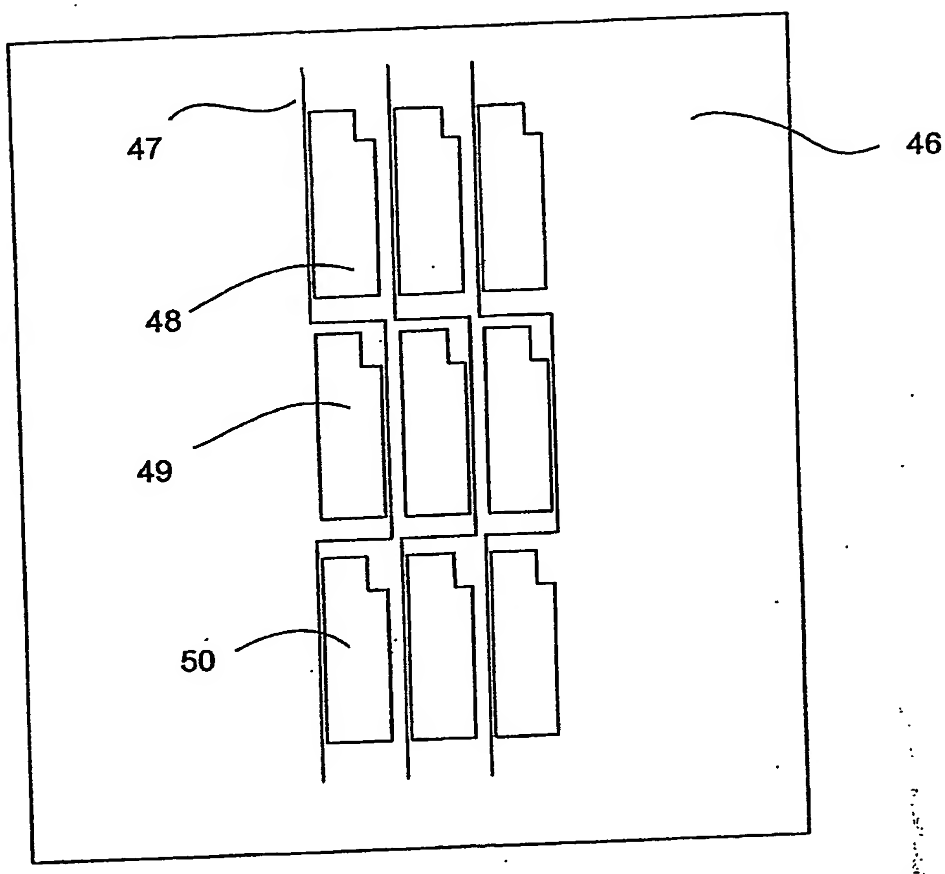


Fig. 10

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